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NGC 4245: one or two bars, and where does the gas inflow stop?

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Abstract. We have studied stellar and gaseous kinematics as well as stellar population properties in the center of the early-type barred galaxy NGC 4245 by means of integral-field spectroscopy. We have found a chemically distinct compact core, more metal-rich by a factor of 2.5 than the bulge, and a ring of young stars with the radius of 300 pc. Current star formation proceeds in this ring; its location corresponds to the inner Lindblad resonance of the large-scale bar. The mean age of stars in the chemically distinct core is significantly younger than the estimate by Sarzi et al. (2005) for the very center, within $R = 0.''25$, made with the HST spectroscopy data. We conclude that the 'chemically distinct core' is in fact an ancient ultra-compact star forming ring with radius less than 100 pc which marks perhaps the past position of the inner Lindblad resonance. In general, the pattern of star formation history in the center of this early-type gas-poor galaxy confirms the predictions of dynamical models for the secular evolution of a stellar-gaseous disk under the influence of a bar.

Key words. galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: individual: NGC 4245

1. Introduction

Secular evolution of disk galaxies is a slow but persistent process that changes the appearance and structure of a galaxy drastically on timescales of a few Gyrs. The main drivers of secular evolution are bars, and the final point where gas accumulates and star formation proceeds is the center of a galaxy. So to study consequences of secular evolution in disk galaxies, we must look at their centers; and to choose the most promising objects where secular evolution has certainly occured we must look at galaxy groups. The groups are good for the secular evolution realisation because the mutual movements of galaxies are not so fast as in clusters, and the space density of galaxies is high, so tidal interaction provoking bar formation, and matter redistribution in a disk, is provided.

NGC 4245 is an early-type disk galaxy (SB(r)0/a, according to NED), of a moderate luminosity ($M_B = -18.74$ according to the

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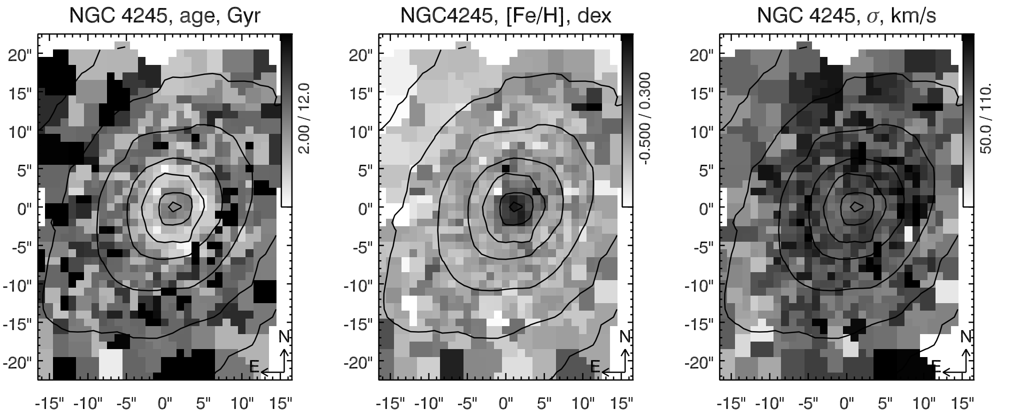

Fig. 1. Results of the fitting of the SAURON spectra for NGC 4245, from the left to the right – SSP-equivalent stellar ages, SSP-equivalent stellar metallicity, and stellar velocity dispersion.

HYPERLEDA), with a large-scale strong bar – a member of a rich, spiral-dominated group Coma I Cloud (Gregory & Thompson 1977). NGC 4245 is located in the dense part of the group, some 100 kpc from the group center and 59 kpc from the giant spiral galaxy NGC 4274. As do all other disk galaxies of the group Coma I Cloud, NGC 4245 demonstrates a strong deficiency of neutral hydrogen (Garcia-Barreto et al. 1994). The ratio of $M(\mathrm{H_2})/M(\mathrm{HI}) \sim 4$ in this galaxy (Gerin & Casoli 1994), and all its gas is concentrated in the circumnuclear region where a spectacular starforming ring is observed. Interestingly, the group Coma I Cloud lacks X-ray intergalactic medium, so the common explanation of the HI deficiency by the interaction with the hot intergalactic medium is not valid in this case. It seems probable that gravitational interactions play the main role in the group. NGC 4245 as a recently formed lenticular galaxy may represent a late product of secular evolution provoked by the strong bar and by the effects of a dense environment.

2. Observations

We analyse here the integral-field spectral data obtained with the Multi-Pupil Fiber Spectrograph (MPFS) of the Russian 6-m telescope and the SAURON data retrieved from the ING Archive of the UK Astronomy Data Center. The former spectrograph (Afanasiev et al. 2001) gives a field of view of $16'' \times 16''$ and a spectral range of 1500 Å with the spectral resolution of 3 Å; the latter (Bacon et al. 2001) – has a field of view of $41'' \times 33''$ with a spectral range of 550 Å under the spectral resolution of 4 Å. The spectra have been fitted in the pixel space by SSP models (Chilingarian et al. 2007), and the kinematic characteristics as well as stellar population parameters have been obtained.

3. Results

The maps of parameters of the stellar population in the central part of NGC 4245 are presented in Fig. 1. We can divide the central part of NGC 4245 into three substructures differing by kinematic and stellar population properties: the central unresolved core which appears to be dynamically cold and chemically distinct, the ring with the radius of $4'' - 6''$ where the emission line Hα is extremely intensive and current star formation proceeds, and the bulge without emission lines seen at $R = 7'' - 10''$ where the maximum stellar velocity dispersion is observed, the stars are old, and the metallicity is subsolar. The comparison of the Lick indices measured by us in these three substructures' MPFS spectra with the SSP models of Thomas et al. (2003) gives the following quantitative

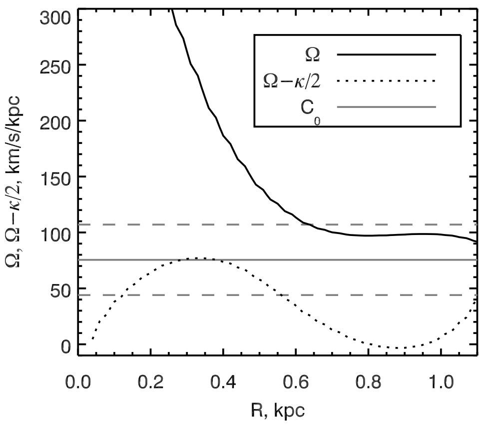

Fig. 2. Positions of the inner Lindblad resonances derived from the analysis of the SAURON line-of-sight velocity map for NGC 4245.

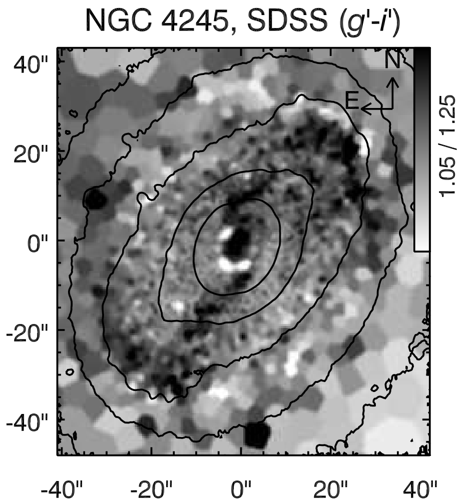

Fig. 3. $g' - i'$ colour map of NGC 4245 built from the SDSS direct images.

results: in the core the metallicity is higher than solar by a factor of 3–5 and the mean stellar age is 2–4 Gyr, in the ring the mean stellar age is 1–2 Gyr, and in the bulge 8–12 Gyr. The fitting of the SAURON spectra with the PEGASE.HR code gives [m/H]= +0.2 and $T_{\mathrm{SSP}} = 6.5$ Gyr in the core, $T_{\mathrm{SSP}} = 2 - 4$ Gyr in the ring, and [m/H]= −0.2 and $T_{\mathrm{SSP}} = 8$ Gyr in the bulge.

4. Discussion

Starforming rings are commonly related to inner Lindblad resonances (ILR) of bars (Buta & Combes 1996). The observational statistics of ring sizes by Buta & Crocker (1993) has established this relation empirically. Later simulations confirmed that gas inflowing along a bar must accumulate just at ILRs (Heller & Shlosman 1996). The starforming ring in NGC 4245 answers all expectations. Fig. 2 helps to determine the ILR radii in this galaxy. We have taken the pattern speed of the bar in NGC 4245 from Treuthardt et al. (2007). With this pattern speed, the galaxy may have two ILRs: the inner one at $R = 5''$ and the outer one at $R = 6''$. The starforming ring is observed just between them as theory predicts (Piner et al. 1995; Buta & Combes 1996).

Fig. 3 demonstrates the $g' - i'$ colour map of NGC 4245 constructed by using the SDSS data. Here we see also a classical signature of gas response to the bar perturbation: thin straight red (dust) lanes border the bar along its whole extension betraying the presence of shocks produced by orbit crowding in the triaxial potential (Athanassoula 1992). Dust fronts end at the starforming ring which is blue at the colour map. The blue starforming ring has three knots which are the bluest and coincide with the Hα condensations – the sites of especially intense star formation; two of them are just at points where the shock fronts meet the ring. Such a picture is typical for star forming rings within bars – see for example a sample by Boker et al. (2008). Theoreticians explain this phenomenon as follows: external disk gas inflows along the bar, meets the dense gas concentration in the ring, produces shocks and provokes star formation at the points of contact, and then these star forming sites are driven by rotation into a complete ring.

According to theory, the gas inflow must stop at ILRs, and no gas supply is allowed inside the ILRs. However our results give evidences that some time ago gas inflow has overcome this obstacle. The stellar core is unresolved with MPFS and SAURON, and so the stellar population within $1'' - 2''$ from the center, is chemically distinct and is also significantly younger than the bulge. So we conclude that there has been secondary star formation burst *inside* $R = 1'' - 2''$, or inside the *present* ILRs, and this star formation burst has needed gas supply to occur. But curiously, this star formation burst was also annular, not nuclear: Sarzi et al. (2005), by analysing the HST spectral data obtained within the aperture of $0\farcs25$, determined for the nucleus of NGC 4245 the stellar age of 12 Gyr and no signs of gas emission. So the ancient star formation burst took place in the ring between $0\farcs25$ ($R = 15$ pc) and $1\farcs5$ ($R = 100$ pc). Did this ring mark the previous location of the ILR? In such case the chemically distinct core found by us maybe a remnant of the starforming ring at the ILR of the (now) dissolved inner bar and may be classified as an 'ultracompact nuclear ring' similar to those which have been discovered recently in some barred galaxies (Comeron et al. 2008). Or may be the nuclear star-forming ring in NGC 4245 changes its radial position as some theoretical considerations predict (Regan & Teuben 2003)? Then, since we know the ages of the SF-rings at $R = 300$ pc and at $R = 20 - 100$ pc, it would be interesting to try to relate possible interactions with neighbouring galaxies with the ring shifts along the radius.

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